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Modeling and Validation of Wide Band Bandpass Filter Using Open-Stub Resonator

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Abstract - In this paper one coplanar wide band bandpass filter (BPF) is designed with end-coupled λ/4 open-stub resonator. This coplanar waveguide (CPW) BPF is designed for passband centre frequency 2.5GHz and 100% fractional bandwidth (FBW) at -3dB. The proposed structure exhibits negligible passband insertion loss, sharp transition from passband to stopband, wide attenuation bandwidth, simple fabrication with reduced size and slow-wave characteristics. Thus, these good properties, wide band, smaller size filters are too much applicable in our modern microwave and millimetre wave communication systems.

Keywords - Coplanar waveguide, bandpass filter, open-stub resonator, RF, microwave, communication system.

1. Introduction

The coplanar waveguide (CPW) technique has long been an attractive subject and a favorite topic of researchers. CPW transmission line currently enjoying renewed interest in the RF and microwave field for their different applications in the microwave and millimeter-wave regime [3], [5], [7]. CPW is also suitable because of its unique structural advantages [1]-[2], [8]-[9]. As the signal line and the ground planes are on the same plane of the substrate so there is no via hole process is needed and the fabrication of the CPW is simpler than that of the microstrip line. Secondly, the CPW provides greater design flexibility because the widths of the slots and signal line of the CPW can be easily adjusted for the determination of the characteristic impedance as compared with the microstrip line.

From transmission line theory, the propagation constant and phase velocity of a lossless transmission line are given, respectively, as $\beta = \omega\sqrt{LC}$ and $v_P = 1/\sqrt{LC}$, where L and C are the inductance and capacitance per unit length along the transmission line. Introducing any periodic structures in the transmission line, drilling any holes in the substrate and etching any structure in the ground plane effectively increase L and C values which are responsible for accomplishing slow-wave propagation and suitable for designing different microwave circuits such as filters, power divider, amplifiers etc.

In this paper, two parallel open-stubs have been used in addition with CPW line. Each stub introduces some inductance and capacitance, as well as changes the electric current distribution of the transmission line [4], [6], [8]-[10]. Two stubs are end coupled and this capacitive coupling is sufficient for providing excellent bandpass filtering response.

II. Bandpass Filter Topology

Figure 1 (a) shows a schematic diagram of the designed bandpass filter structure for 2.5 GHz centre frequency. It consists of two symmetrical parts. Each part is composed of a *λ/4* conductor section followed by two parallel open-stubs of length *b*. These two parts are capacitively coupled through the gap *c*. The dimensions of the proposed structure are as follows: length L = 20 mm, width H = 20 mm, a = 6 mm, b = 6mm, c = 0.4mm.

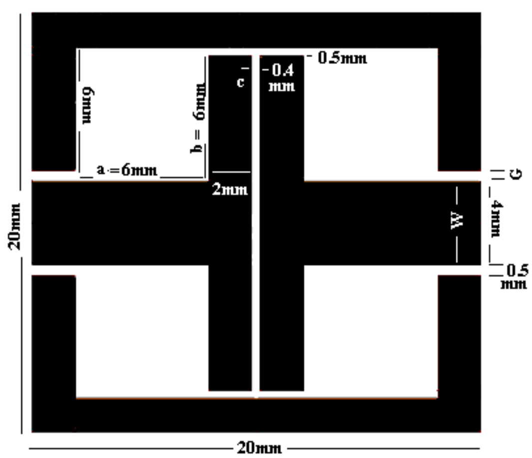

Fig.1(a) schematic diagram

The CPW line used in this filter was designed for a characteristic impedance of 50 Ω. This impedance corresponds to G = 0.5 mm and W = 0.4 mm. The electromagnetic simulation result for the bandpass filter is shown in Figure 1 (b). the simulation has been done with the help of method of moment (MoM) based IE3D EM simulator. The filter provides passband centre frequency, f_0, at 2.46 GHz and it resembles two poles, f_1 and f_2, in the pass-band ranging from 1.218 GHz to 3.71 GHz and has a steep transition from the pass-band to the stop-band. The filter has a -3 dB bandwidth of 2.5 GHz. At the same time the filter shows almost 100% fractional bandwidth at -3 dB. The current distribution density at 2.5 GHz and 4 GHz are shown in the Figure 1(c) and Figure 1(d).

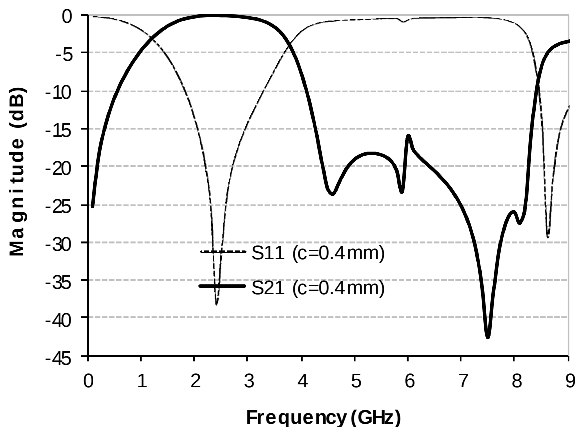

Fig.1(b) Scattering parameters

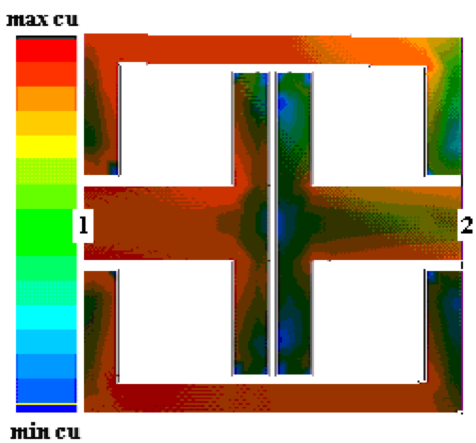

Fig.1(c) current distribution density at 2.5 GHz

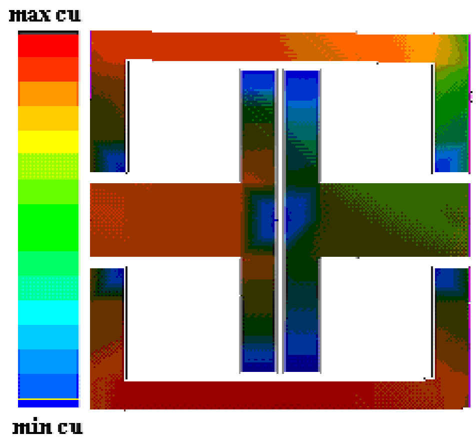

Fig.1(d) current distribution density at 4 GHz

3. EQUIVALENT CIRCUIT MODEL

The filter structure has also been modeled with lumped-element components. Thus, the equivalent circuit of the proposed structure can be represented by the Fig. 2(a). The conductor section is modeled as a series inductor Ls with capacitor Cs while the parallel $\lambda/4$ stubs are modeled as an inductor Lp in series with a capacitance Cp. The gap between the two sections of the filter is modeled as a series capacitance C_0. Table. 1 shows the values of the components of the equivalent circuit model. Fig. 2(b) shows the frequency response results obtained with EM simulation and the lumped-element model.

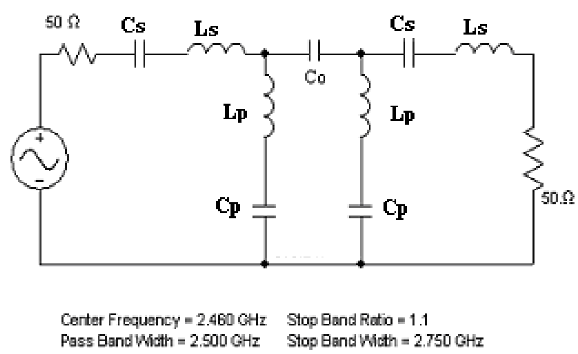

Fig. 2(a) Circuit model

Table (1) components of the equivalent circuit model

Ls (pf)	Cs (nH)	Lp(pf)	Cp (nH)	Co(pf)
1.073	3.9	12.204	336.5	0.462

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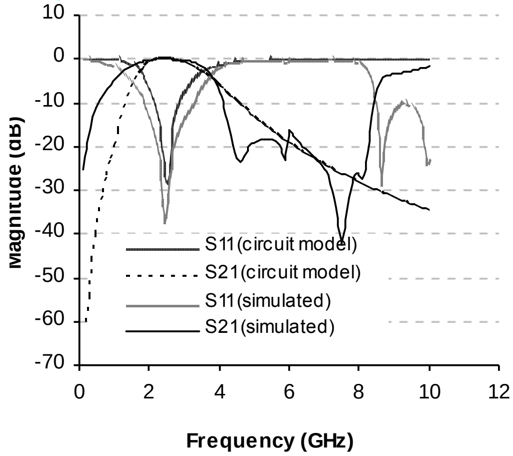

Fig.2(b) Scattering parameters

4. Parametric Study and Tunning

(a) Variation of gap (c)

Figure. 3 shows the frequency response of the designed filter for values of the gap *c* = 0.4 mm, *c* = 0.8 mm, *c* = 1.2 mm and *c* = 1.6 mm, while values of *a* and *b* were kept constant. The gap *c* is changed by the changing of the width of the open-stubs. Variation of the gap *c* affects slightly the transmission within the pass-band, while the reflection significantly depends on *c*. In particular, a smaller value for *c* makes the transition from the pass-band to the stop-band steeper. It is also observed -3dB fractional bandwidth, (FBW=$((f_1\text{-}f_2)/fo)\times100\%$) varies inversely with gap *c*.

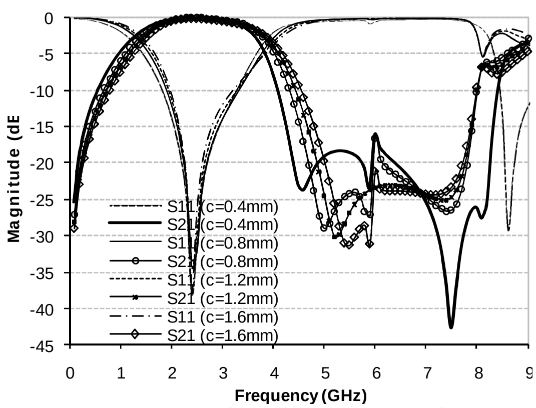

Fig.3. S11 and S21 for different values of gap, c

The parametric study due to different values of gap, c is shown in Table 2.

Table (2) Variation of different properties with gap,c

Gap,c (mm)	Centre frequency, *fo* (GHz)	Lower cut-off f_1(GHz)	Upper cut-off f_2(GHz)	FBW (%)
0.4	2.476	1.212	3.737	102
0.8	2.596	1.313	3.878	98.8
1.2	2.7	1.420	3.92	92.6
1.6	2.73	1.475	3.98	91.8

Graphical representation of centre frequency, *fo* , cut-off frequencies and FBW with 'c' are shown in fig 4(a), 4(b) and 4(c) respectively.

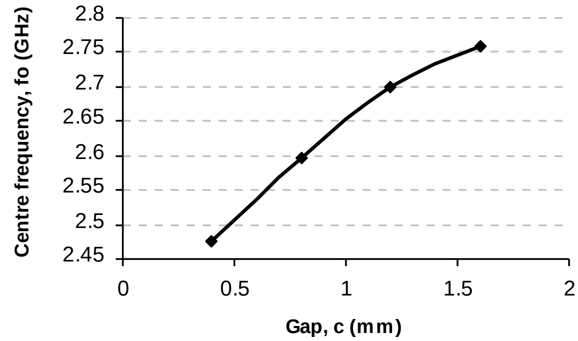

Fig.4(a) Variation of '*fo*' with 'c'

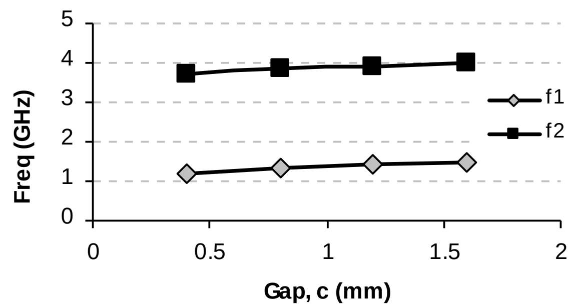

Fig.4(b) Variation of 'f_1 & f_2' with 'c'

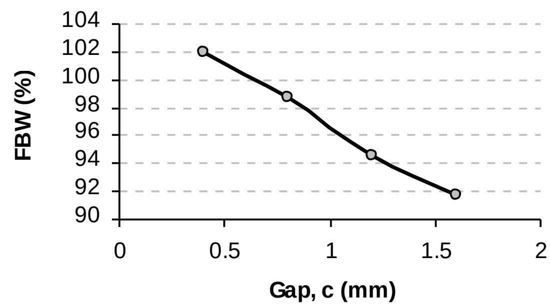

Fig.4(c) Variation of 'FBW' with 'c'

Mathematically, with the curve fitting of fig 4(a) and fig 4(c) it is possible to find out the following equations

$$Y = 52.496X_1^3 - 405.71X_1^2 + 1048.1X_1 - 904.2 \quad \text{...} (1)$$

and

$$Y = -0.0011X_2^3 + 0.3095X_2^2 - 30.171X_2 + 984.34 \quad \text{...}(2)$$

where, Y, X_1 and X_2 corresponding to Gap width, 'c' (in mm), centre frequency, '*fo*' (in GHz) and -3dB FBW (in %) respectively.

Thus, from the above discussion, utilizing equ (1) and equ (2) it is possible for a user to optimized the filter

dimension by finding the dimension of 'c' for specified values of centre frequency, '*fo*' (in GHz) and -3dB FBW (in %).

(b) Variation of conductor Length (a)

Figure 5 shows the characteristics of the filter structure for different values of the length of the conductor section '*a*' (see Figure 1). An increase of this geometric parameter leads to a slight decrease of the bandwidth, but the reflection is improved. '*a*' mainly affects the inductances *L*s of the lumped-element model, as shown in Figure 2. As '*a*' decreases, the pass-band is shifted to higher frequencies. It should be mentioned that the width of the ground plane at the input and output ports are also changing with the parameter '*a*'.

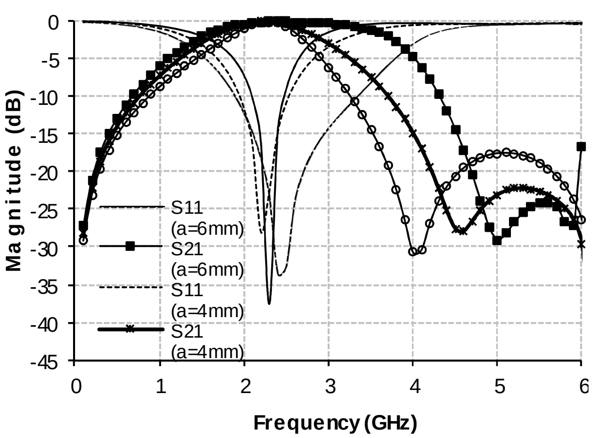

Fig.5. S11 and S21 for different values of conductor length, '*a*'

The parametric study due to different values of conductor length, '*a*' is shown in Table 3.

Table (3) Variation of different properties with conductor length, '*a*'

Length, '*a*' (mm)	Centre frequency, *fo* (GHz)	Lower cut-off f_1(GHz)	Upper cut-off f_2(GHz)	FBW (%)
2	2.222	1.697	2.747	47.254
4	2.43	1.475	3.01	68.44
6	2.596	1.313	3.878	98.8

Graphical representation of centre frequency, *fo,* cut-off frequencies and FBW with '*a*' are shown in fig 6(a), 6(b) and 6(c) respectively.

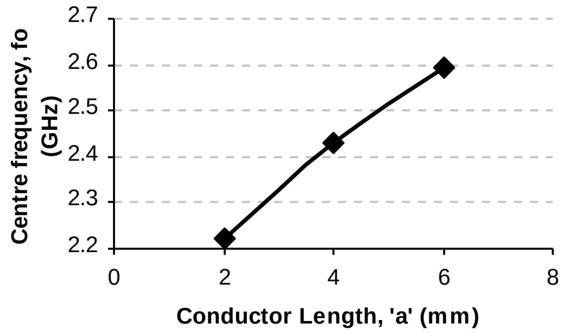

Fig.6(a) Variation of '*fo*' with '*a*'

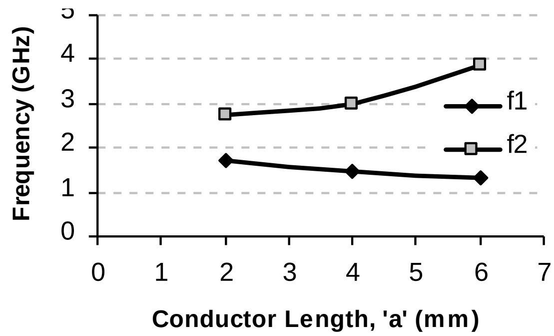

Fig.6(b) Variation of 'f_1& f_2' with '*a*'

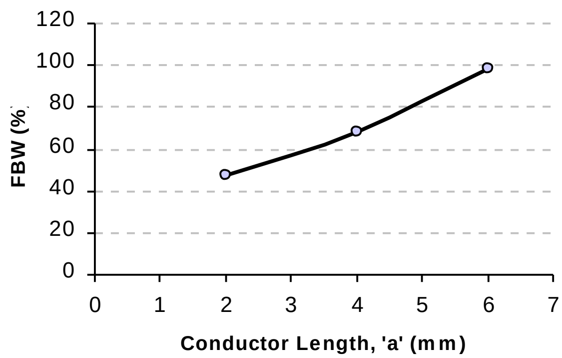

Fig.6(c) Variation of 'FBW' with '*a*'

Mathematically, with the curve fitting of fig 6(a) and fig 6(c) it is possible to find out the following equations

$$Y = 6.5048X_1^2 - 20.645X_1 + 15.757 \text{......(3)}$$

and

$$Y = -0.0006X_2^2 + 0.1584X_2 - 4.2506 \text{....(4)}$$

where, Y, X_1 and X_2 corresponding to Gap width, 'c' (in mm), centre frequency, 'fo' (in GHz) and -3dB FBW (in %) respectively.

Thus, from the above discussion, utilizing equ (3) and equ (4) it is possible for a user to optimize the filter dimension by finding the dimension of '*a*' for specified values of centre frequency, '*fo*' (in GHz) and -3dB FBW (in %).

5. Measurement and Discussion

The proposed structure has been fabricated with the substrate FR4 of substrate height 1.58mm, dielectric constant 4.4 and loss tangent 0.002. the photonic view of the bandpass filter with conductor back coplanar waveguide (CB-CPW) open stub resonator is shown in the following Fig.7.

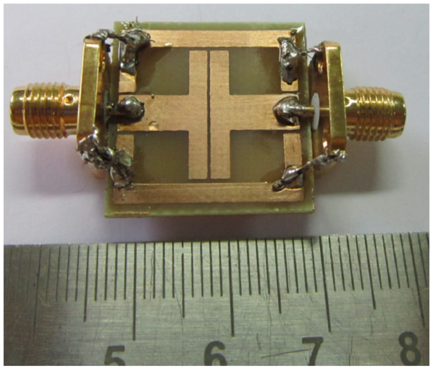

Fig.7(a) Top plane

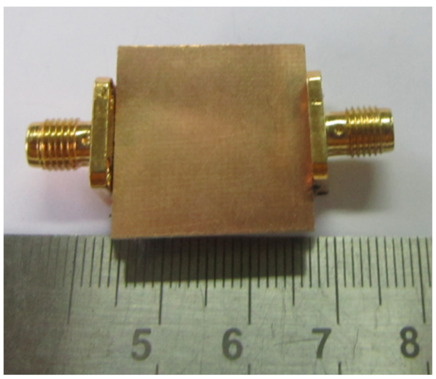

Fig.7(b) Bottom plane (Conductor back)

The proposed structure has been measured with an Agilent make vector network analyzer of model N5230A. frequency response of the structure is shown in the Fig. 8.

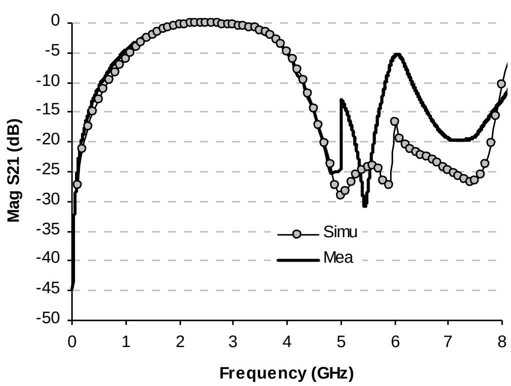

Fig.8. Scattering parameters

From the above frequency analysis it can be observed that both simulated and measured response provides bandpass filtering response with passband centre frequency around 2.5GHz and almost 100% fractional bandwidth (FBW) at -3dB. Therefore, there is a good agreement between the EM simulated and measurement responses.

6. Conclusion

In this paper one wide band bandpass filter has been designed using end coupled CPW transmission line. The coupling has been improved by using open stubs and minimizing the coupling gap. The proposed structure provides a bandpass filtering response with centre frequency 2.5 GHz, 4.5GHz passband bandwidth at -20dB, 100% FBW at -3dB, negligible passband insertion loss and sharpness factors of almost 28.23 dB/GHz and 27.04 dB/GHz at the rising and the falling edges respectively. The concept of tunable BPF has been provided by varying the dimensions of the proposed structure. However, the simple CB-CPW based open stub end coupled BPF is too much applicable in our modern microwave and millimeter wave communication systems.

7. Acknowledgement

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8. References

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